Fermi National Accelerator Laboratory

TM-1423
2967.000

A METHOD TO RAPIDLY TUNE THE HALO SPOILERS OF THE TEVATRON MUON BEAM

Y. Ojeda
University of New Mexico
Albuquerque, NM

B. Scott
Purdue University
West Lafayette, IN

A. Malensek and J. G. Morfin
Fermi National Accelerator Laboratory
Batavia, IL

September 1986

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

A Method to Rapidly Tune the Halo Spoilers of the Tevatron Muon Beam

Y. Ojeda
University of New Mexico
Albuquerque, NM

B. Scott
Purdue University
West Lafayette, IN

A. Malensek and J. G. Morfin
Fermi National Accelerator Laboratory
Batavia, IL

One of the more difficult tasks in designing high energy muon beam lines is keeping "halo" muons to a minimum. Halo muons are those muons which enter the aperature of an experiment without having passed through the momentum tagging system. Their momentum is thus unknown and not only is any interaction they might have with the experimental target useless, but they can also introduce confusion to pattern recognition and the subsequent analysis. A large fraction of the effort that has gone into the design of the Tevatron Muon Beam[1](TMB) has had the objective of minimizing this halo while maximizing the flux of useful muons.

The layout of the elements of the muon FODO[1] of the TMB is shown in Fig 1. It is this section of the beam where the attempt is made to rid the beam of halo. Since muons interact via the Electroweak force, it is impractical to try and absorb them as one would absorb hadrons. An active shield has been constructed which forms a sharp magnetic edge around the central core of useful muons and sweeps the envelope of halo muons radially away from beam center. Two types of halo scrapers have been employed in this shield; conventional toroidal magnets and a newly developed magnetic element called "mupipe". The conventional toroids are located in enclosure NMO (see Fig. 1) which is approximately 600 feet upstream of the start of the E-665[2] Spectrometer. There are two toroids, one 30 feet long and 88" in diameter while the other is 20 feet long and 118" in diameter. The toroids operate with a central field of 17 Kgauss.

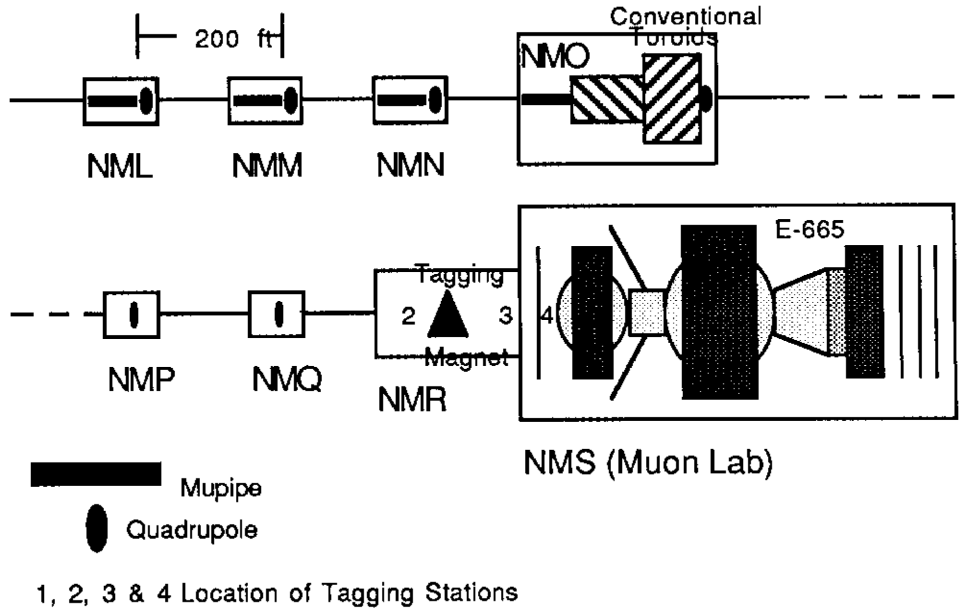

Fig. 1 Schematic Layout of the Muon FODO Elements

Upstream of these toroids, in enclosures NML, NMM, NMN and the start of NMO, are four sections of mupipe. Mupipe is a tightly wound coil of transformer steel with inner diameter varying between 4.5 and 5.0 inches and outer diameter of 7.5 inches. In the first three enclosures there are 30 feet lengths of mupipe while in NMO there is a 20 foot length. Because of the type of steel used, the magnetic field attains a strength of 18 Kgauss within mils of the inner surface of the pipe. With this field, <u>any halo particle which enters the mupipe is forced radially outward before it can multiple scatter back toward beam center.</u> These four sections of mupipe start the purging of the halo muons and the large diameter conventional toroids then complete the job.

Of the four sections of mupipe, the first (NML) and the last (NMO) are immovable. However, both the upstream and downstream ends of the mupipes in NMM and NMN can be moved independently in the plane perpendicular to the beam as depicted in Fig. 2. Obviously, with eight degrees of motion, it would **consume days (weeks?) of valuable beam time** to attempt to tune the mupipe system by systematic measurements over the full range (± 2 inches) of each of the eight coordinates. In light of

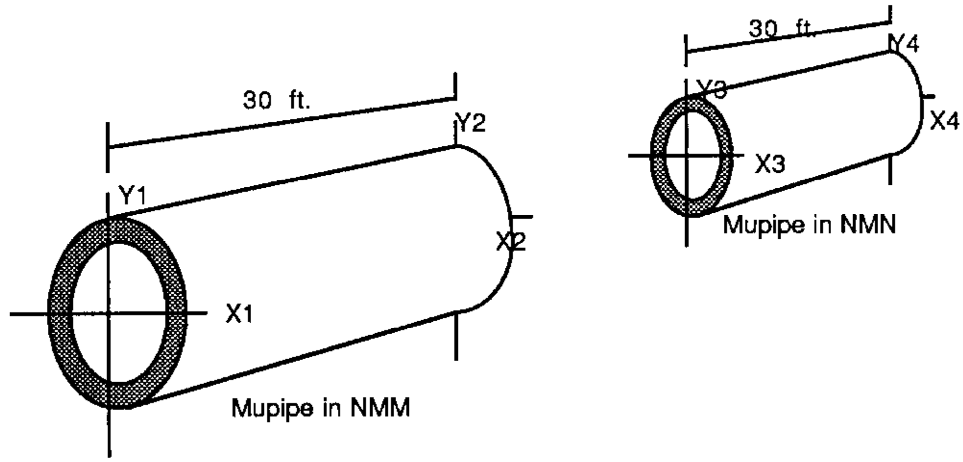

Fig. 2 The eight degrees of motion of the movable mupipe system

this, an attempt has been made to formulate an algorithm which will take a small set of measured values and from them predict the required positions of the two sections of mupipe to obtain maximum beam and minimum halo. The basic principle of the algorithm is to: measure the muon and halo yields at a representative subset of coordinates $(X_i Y_i)$; employ a fitting program to find a functional form for the yields in terms of the coordinates and finally maximize (or minimize) the function in terms of the $(X_i Y_i)$.

To test the algorithm, the Monte Carlo program HALO[3] was used to predict the halo and muon yield for a given orientation of the two movable sections of mupipe. It was determined that to get a statistically significant (5%) sample of halo muons it was necessary to generate 250,000 parent particles. Furthermore, since all bending in the TMB occurs in the horizontal plane, so that the vertical distribution of halo and muon particles is relatively symmetric, it was decided to treat the horizontal and vertical movements of the mupipe independently. For the horizontal case, the results of 54 halo runs (for $-1'' < X_i < +1''$) are shown in Table I. The general functional form, to which the 55 points were fit, is:

$$N_0 + \sum_{i=1,4} \{A_i X_i + B_i X_i^2 + C_i X_i^3 + [\sum_{j=1,4}^{j \neq i} D_{ij} X_i X_j + E_{ij} X_i X_j^2 + \sum_{k=1,4}^{k \neq j \neq i} F_{ijk} X_i X_j X_k] \} \quad (1)$$

The parameters A, B, and C, the non-crossterm contributions, were fit by setting three of the four X_i to 0.0 and fitting for the fourth. The behaviour of the muon intensity (expressed in arbitrary units) is shown in Fig. 3.

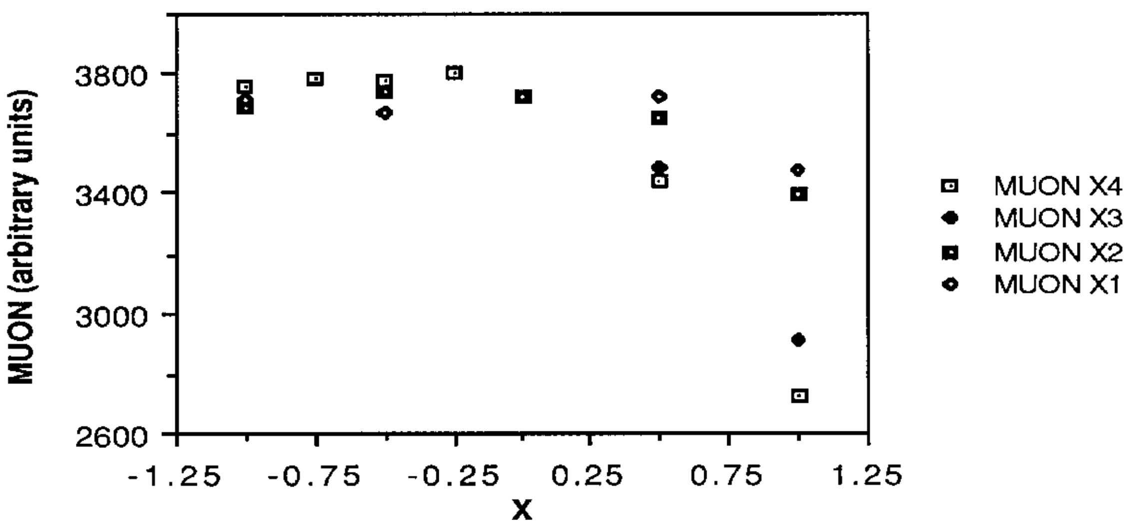

Fig. 3a The dependence of the muon flux on X_i when X_j=X_k=X_l=0.0

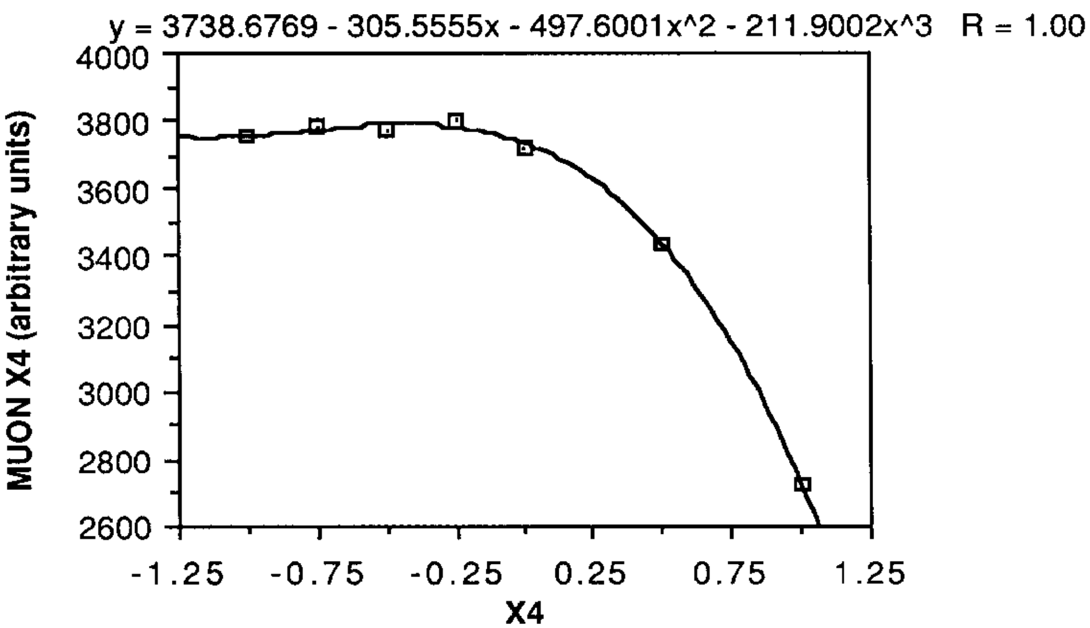

Fig 3b An example of a fit of the muon flux to X_4 behaviour. The expression at the top comes directly from the fitting program.

The explicit form of the non crossterms of expression (1) are:

$$
\begin{array}{lllll}
 & & A_i & B_i & C_i \\
\varphi(\mu) = 3724.7 & + & 110.3X_1 & - 132.3X_1^2 & - 229.3X_1^3 \\
\varphi(\mu) = 3735.7 & - & 65.3X_2 & - 193.4X_2^2 & - 78.7X_2^3 \\
\varphi(\mu) = 3715.8 & - & 216.7X_3 & - 404.9X_3^2 & - 185.3X_3^3 \\
\varphi(\mu) = 3738.7 & - & 305.6X_4 & - 497.6X_4^2 & - 211.9X_4^3
\end{array}
$$

The muon flux intensity is much more sensitive to the position of the mupipe in NMN (X_3 and X_4) than in NMM where the variation in flux is comparatively flat with respect to the horizontal position.

The behaviour of the halo under the same conditions is shown in Fig. 4. As can be seen, the shape of the X-dependence is the same as for the muon flux. However the relative change in halo over this X-range is only about half of the **nearly 30%** change in the muon flux over the same range. It appears that the tuning of the mupipe is more an exercise in maximizing the muon flux than minimizing the halo, although decreasing the halo by a further 15% is a significant saving in deadtime for the experiment.

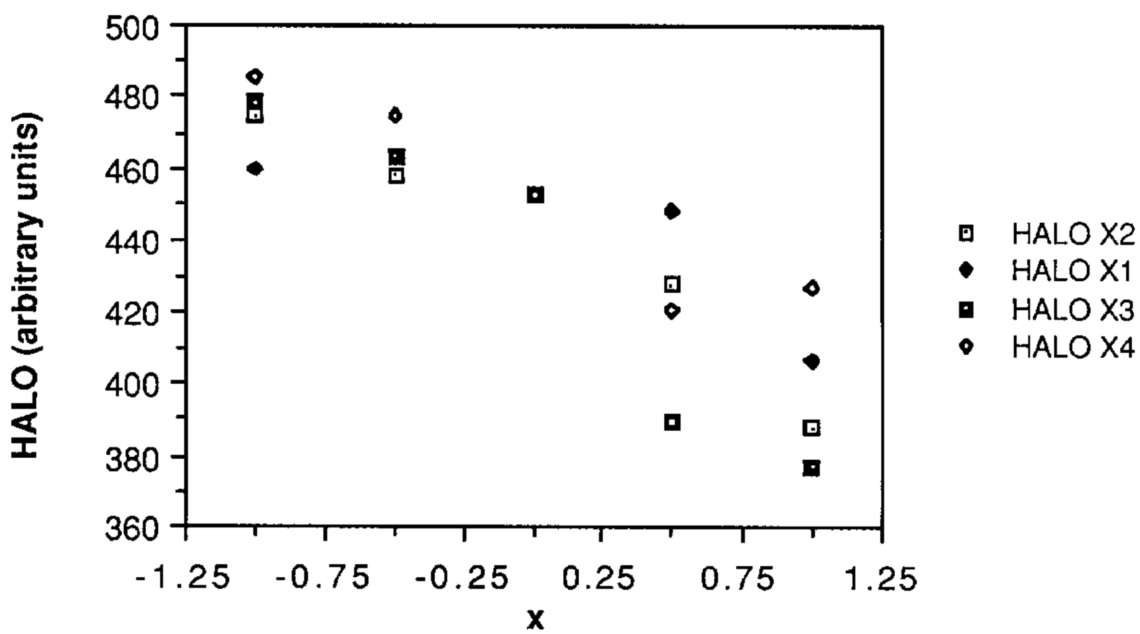

Fig. 4 The dependence of the halo on X_i when $X_j = X_k = X_l = 0.0$

The grand fit to all 54 points was performed with both the minimum χ^2 fitting programs DUBNAL[4] and MINUIT[5] to see if there was a difference in the amount of time required for the fit or with the fitted variables themselves. The results showed no significant differences between the two programs. The procedure used in fitting the variables from expression (1) was to start with an overall fit to all D_{ij}, E_{ij} and F_{ijk} included in the expression, and then to eliminate those terms that had little or no effect on the fit as indicated by the relative error of the fitted value. After the first round, all terms with relative error greater than 100% were eliminated. Successive rounds had cutoffs of 75%, 50% and finally 25%. The final fit had a χ^2 of 52.9 for 49 degrees of freedom and yielded the following expression:

$$\begin{aligned}\varphi(\mu) = {} & 3788.7 + 110.3X_1 - 132.3X_1^2 - 229.3X_1^3 - 65.3X_2 \\ & - 193.4X_2^2 - 78.7X_2^3 - 216.7X_3 - 404.9X_3^2 - 185.3X_3^3 \\ & - 305.6X_4 - 497.6X_4^2 - 211.9X_4^3 + 275.2X_3X_4 + 294.3X_3X_4^2 \\ & + 335.0X_4X_3^2 + 217.8X_2X_1^2 \end{aligned} \tag{2}$$

As the χ^2 indicates, the fit is quite good. This is confirmed in Fig. 5 which shows the fitted value vs the input value. There are only a few points that are more than a standard deviation away from the diagonal line which indicates a perfect fit.

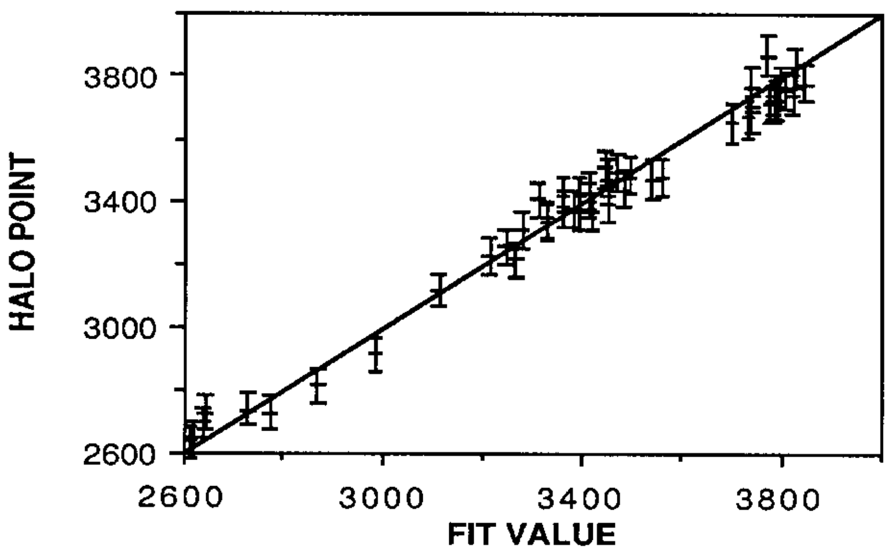

Fig. 5 The HALO input values and the corresponding fitted value using expression (2).

To maximize the muon flux, the expression 1 / $\varphi(\mu)$, where $\varphi(\mu)$ is given by expression (2) was minimized with the MINUIT minimization program. The result of this minimization was then used as input to a program that uses an iterative technique to determine an exact solution to a system of nonlinear equations. The final results indicate that a maximum muon flux of 3904 could be obtained by placing the two mupipes in the following horizontal configuration:

$$X_1 = +.23''$$
$$X_2 = -.16''$$
$$X_3 = -.31''$$
$$X_4 = -.38'' \quad .$$

This is a 5% increase in flux copmpared to the nominal beam center position of (0,0,0,0).

As mentioned, the solution for the vertical movement of the mupipe is somewhat less complicated since the muon flux is much more symmetric with respect to y than it is with respect to x. This is shown in Fig. 6.

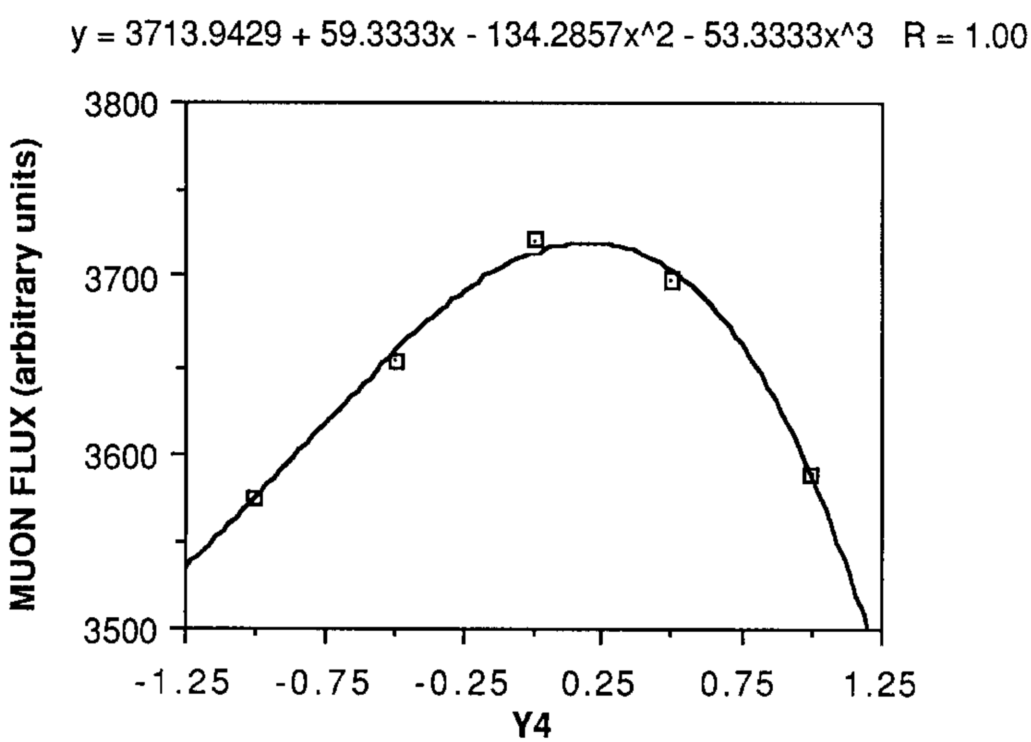

Fig. 6 The relation of the muon flux to the vertical position Y_4

It should also be clear from Fig. 6 that the vertical solution is much less sensitve to position than the horizontal case. Whereas the muon intensity varys by $\approx$ 30% over the $\pm$ 1 inch range of X, the variation in intensity as a function of Y is only **4%!** The result of the overall fit (χ^2 = 40.5 for 39 degrees of freedom) was a much simpler expression:

$$\varphi(\mu) = 3691.5 - 241.7Y_1^2 - 291.5Y_2^2 - 45.0Y_3^2 - 136.0Y_4^2 + 218.9Y_1Y_2 \\ + 16.9Y_1 + 9.7Y_2 - 19.8Y_3 + 2.4Y_4$$

When this result was treated in a manner similar to the horizontal case, it was found that the ideal position of the mupipes in the vertical plane was consistent with nominal beam center (Y_1=Y_2=Y_3=Y_4 = 0.0). However, due to the limited sensitivity of the intensity with respect to the vertical position, there are large tolerances on these positions.

These results for the vertical and horizontal cases were tested by making a final HALO run with the offsets of the mupipes in NMM and NMN set to the above positions. The results show that the flux actually increases by about 3%. It should be emphasized that the significant result of this exercise is not that a few percent increase in flux could be found, but rather that **the method successfully finds a maximum muon flux.** The actual beamline, as opposed to the HALO model, will not be perfectly alligned. Nor will all of the magnetic elements operate at the ideal field strength. All of the uncertainties could conspire to yield a much larger difference between the nominal beam center and the position of maximum flux. In this case, the proposed method will provide a means for quickly obtaining the maximum flux possible while still maintaining a low halo to beam ratio.

REFERENCES

1. A. Malensek and J.G.Morfin; *The Tevatron Muon Beam: A High Intensity Beam with Well Defined Polarization*; Fermilab TM-1193; July, 1983.

2. E-665 Collaboration; *Muon Scattering with Hadron Detection at the Tevatron;* Fermilab Proposal E-665.

3. C. Iselin; *HALO, A Computer Program to Calculate Muon Halo;* CERN 74-17; August, 1974.

4. G. Takhtamyshev; *DUBNAL;* Fermilab PM-0038; June, 1975.

5. M. Roos; *MINUIT;* Fermilab PM 0020; June, 1985.

TABLE I - Results of HALO for horizontal configurations

Muons	X_1(inches)	X_2	X_3	X_4
2461	1.0	1.0	0.0	1.0
2481	1.0	1.0	1.0	1.0
2536	0.5	1.0	0.0	1.0
2553	0.5	1.0	0.5	1.0
2588	0.0	1.0	0.0	1.0
2591	0.0	1.0	1.0	1.0
2619	1.0	0.0	0.0	1.0
2632	1.0	1.0	1.0	0.0
2649	1.0	0.0	1.0	1.0
2695	-0.5	1.0	1.0	0.0
2722	0.0	0.0	0.0	1.0
2723	0.0	1.0	1.0	0.0
2738	1.0	0.0	1.0	0.0
2814	0.0	0.0	1.0	1.0
2910	0.0	0.0	1.0	0.0
3118	0.5	1.0	0.5	0.5
3216	0.5	1.0	0.5	0.0
3226	0.5	1.0	0.5	-1.0
3258	0.5	1.0	0.5	-0.5
3312	-0.5	0.5	0.5	0.5
3338	-0.5	0.5	-0.5	0.5
3347	0.5	0.5	0.5	0.5
3367	0.0	0.5	0.0	0.5
3368	1.0	1.0	0.0	0.0
3376	0.5	0.5	-0.5	0.5
3381	0.5	-0.5	0.5	0.5
3396	0.0	1.0	0.0	0.0
3407	0.5	-0.5	-0.5	0.5
3411	-0.5	-0.5	0.5	0.5
3421	-0.5	-0.5	-0.5	0.5
3423	0.0	-0.5	0.5	0.5
3432	-0.5	0.5	0.5	-0.5
3442	0.0	0.0	0.0	0.5
3473	1.0	0.0	0.0	0.0
3477	1.0	-0.5	-0.5	0.0
3479	0.0	0.0	0.5	0.0
3486	0.5	-0.5	0.5	-0.5

Muons	X_1(inches)	X_2	X_3	X_4
3493	0.5	0.5	0.5	-0.5
3508	-0.5	-0.5	0.5	-0.5
3654	0.0	0.5	0.0	0.0
3667	-0.5	0.0	0.0	0.0
3684	0.0	-1.0	0.0	0.0
3711	-1.0	0.0	0.0	0.0
3714	0.0	0.0	-1.0	0.0
3720	0.5	0.0	0.0	0.0
3722	0.0	0.0	0.0	0.0
3739	0.0	-0.5	0.0	0.0
3742	0.0	0.0	-0.5	0.0
3755	0.0	0.0	0.0	-1.0
3768	-0.5	0.5	-0.5	-0.5
3771	0.5	0.5	-0.5	-0.5
3781	0.0	0.0	0.0	-0.5
3828	0.5	-0.5	-0.5	-0.5
3870	-0.5	-0.5	-0.5	-0.5